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Implementing CIDOC CRM Search Based on Fundamental Relations and OWLIM Rules

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Presentation Outline

- Background and significance of CIDOC CRM
- Fundamental Concepts and Relations
- Example: Thing from Place: definition, graphical (network representation), SPARQL query
- Corrections and rationalization of FRs
- Inverses, Transitive properties, no Reflexive closure
- Parallel-Serial networks, decomposing a FR into sub-FRs, implementing with RDFS and OWL
- OWLIM and OWLIM Rules
- FR Implementation, Performance

Ontotext Cultural Heritage Projects/Clients

- Clients: UK, KR, SE, NL, BG, US

The National Archives
YALE CENTER FOR BRITISH ART
THE BRITISH MUSEUM
de Bibliotheek
ITCC
GÖTEBORGS STADSMUSEUM

- Research projects executed by Ontotext

PrestoSpace
MOLTO
Research SPACE
europeana think culture

- Projects using OWLIM: EU, PL, JP

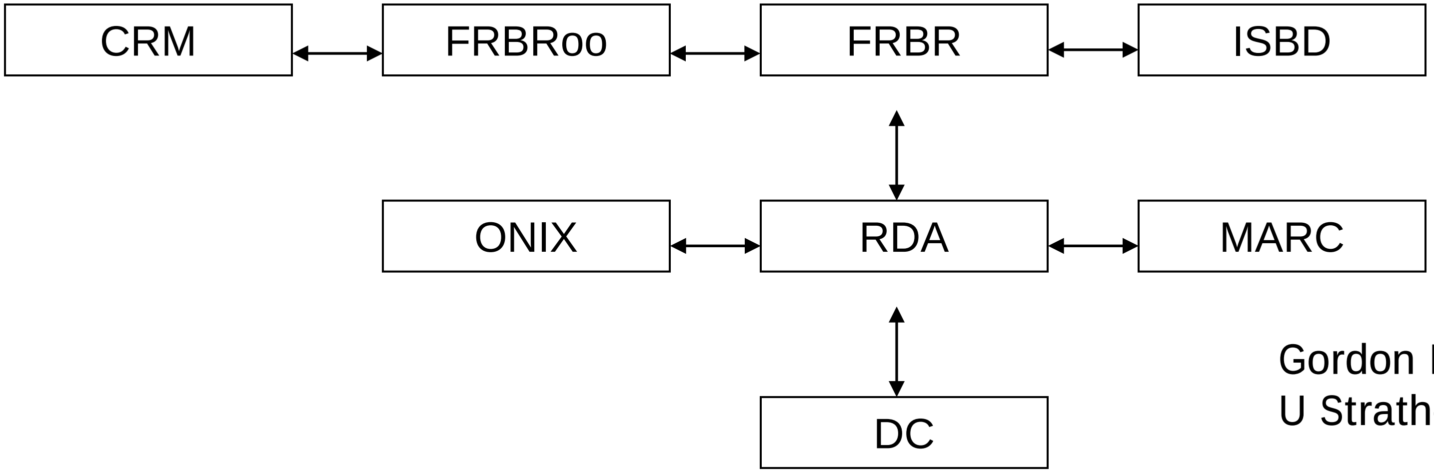
CHARISMA
3D·COFORM Tools & Expertise for 3D Collection Formation
CYFROWE MUZEUM NARODOWE W WARSZAWIE
NII
LODAC

CIDOC CRM

- Created by International Committee for Documentation (CIDOC) of International Council of Museums (ICOM)
  - More than 10y of development, official standard ISO 21127:2006
  - Available at http://www.cidoc-crm.org/
  - Maintained by CRM SIG, crm-sig@ics.forth.gr
- Provides a common semantic framework to which any CH data can be mapped
  - Intended to promote shared understanding of CH data and a "semantic glue" to mediate between different CH sources
  - Few classes (82) and properties (142); quite expressive because it is abstract
  - Original focus: history, archaeology, cultural heritage (CH)
  - Used in various projects, including libraries, archives, museums

Importance of CRM

- CIDOC CRM can map and subsume various domain specific standards, thus allowing to compare, unify and inter-map them
  - E.g. influenced LIDO (events), EDM (subjects, events), mapped EAD, mapped UNIMARC, created FRBR as ontology (FRBRoo), etc
- Everything is connected… at the community (human) and technical (Semantic Web) levels



Gordon Dunsire,
U Strathclyde

Ontotext CRM Experience

- FP7 MOLTO: museum data is based on CRM
  - Multilingual Online Translation. Knowledge infrastructure, interoperability between natural language and structured queries,
  - Museum object descriptions in 15 languages. Gotehnburg Museum case
- ResearchSpace project of the British Museum is based on CRM
  - Advising British Museum and Yale Center for British Art on representing their collections in CRM
- Providing feedback and contributing to RDF definition of CRM
- Implementing CRM search based on Fundamental Relations

CIDOC CRM SEARCH

Fundamental Concepts and Relations (FC, FR)

- CRM data is usually represented in semantic web format (RDF) and comprises complex graphs of nodes and properties.
  - How can a user can search through such complex graphs? The number of possible combinations is staggering.
- New Framework for Querying Semantic Networks (FORTH TR419, 2011)
  - "Compresses" the semantic network by mapping many CRM entity classes to a few "Fundamental Concepts" (FC) : **Thing, Place, Actor, Event/Time, Concept/Type**
  - Maps whole networks of CRM properties to fewer "Fundamental Relations" (FR)
  - FC and FRs serve as a "search index" over the CRM semantic web and allow the user to use a simpler query vocabulary.
  - FR categories include: **type, part, from/generator, similar/same, met, refers/about, borders/overlaps, by** and some of their inverses
  - Matrix declares 114 FRs (18 of them very similar) and 18 "specialization FRs" (e.g. Thing **acquired at** Place is specialization/part of Thing **from** Place)
- Fundamental Categories and Relationships for intuitive querying CIDOC-CRM based repositories (FORTH TR-429, Apr 2012, 153 pages)
  - Defines FRs over all combinations of FCs

FR by FC Matrix

Domain (select)	Range(query parameter)				
	Thing	Actor	Place	Event	Time
Thing	8.has met 9.refers to or is about 10.is referred to by 3.has part 7.is similar or same with 5. from 4.is part of was made from	8.has met 5.from 9.refers to or is about 10.is referred to by 12.by Used by Created by Modified by Found or acquired by	9.refers to 10.is referred to at 5.from Used at Created at Found or acquired at Was created/produced by person from Is/was located at	9.refers to 10.is referred to by 5.from Destroyed in Created in Modified in Used in	5.from Destroyed on Created on Modified on Used on
Actor	8.has met 6.is owner or creator of 9. refers to 10.is referred by	4.is member of 3.has member 8. has met 5.has generator 6.is generator of 9.refers to 10.is referred by	8.has met 5.from 9.refers to 10.is referred to at	9.refers to 10.is referred to by 5.from 8.has met Brought into existence at Taken out of existence at Performed action at Influenced	9.refers to 5.from 8.has met Brought into existence at Taken out of existence at Performed action at Influenced
Place	8.has met 6.Is origin of 9.refers to or is about 10.is referred by	8.has met 6.Is origin of 9.refers to or is about 10.is referred by 8.has met	4.is part of 3.has part 11.borders or overlaps with	9.refers to 10.is referred by 8.has met	5.from 10.refers to 8.has met
Event	6.is origin of 10.is referred by 9.refers to or is about 8.has met created destroyed modified used	12.by 10.is referred by 9.refers to or is about 8.has met brought into existence took out of existence	9.refers to or is about 10. is referred to at 5.from	9.refers to or is about 10.is referred by 3.has part 5.from	9.refers to or is about 5.from starts ends has duration

Thing from Place: A Sample FR

All alternatives through which a Thing's **origin** can be related to Place

a Thing (part of another Thing)* is considered to be "from" Place if it:

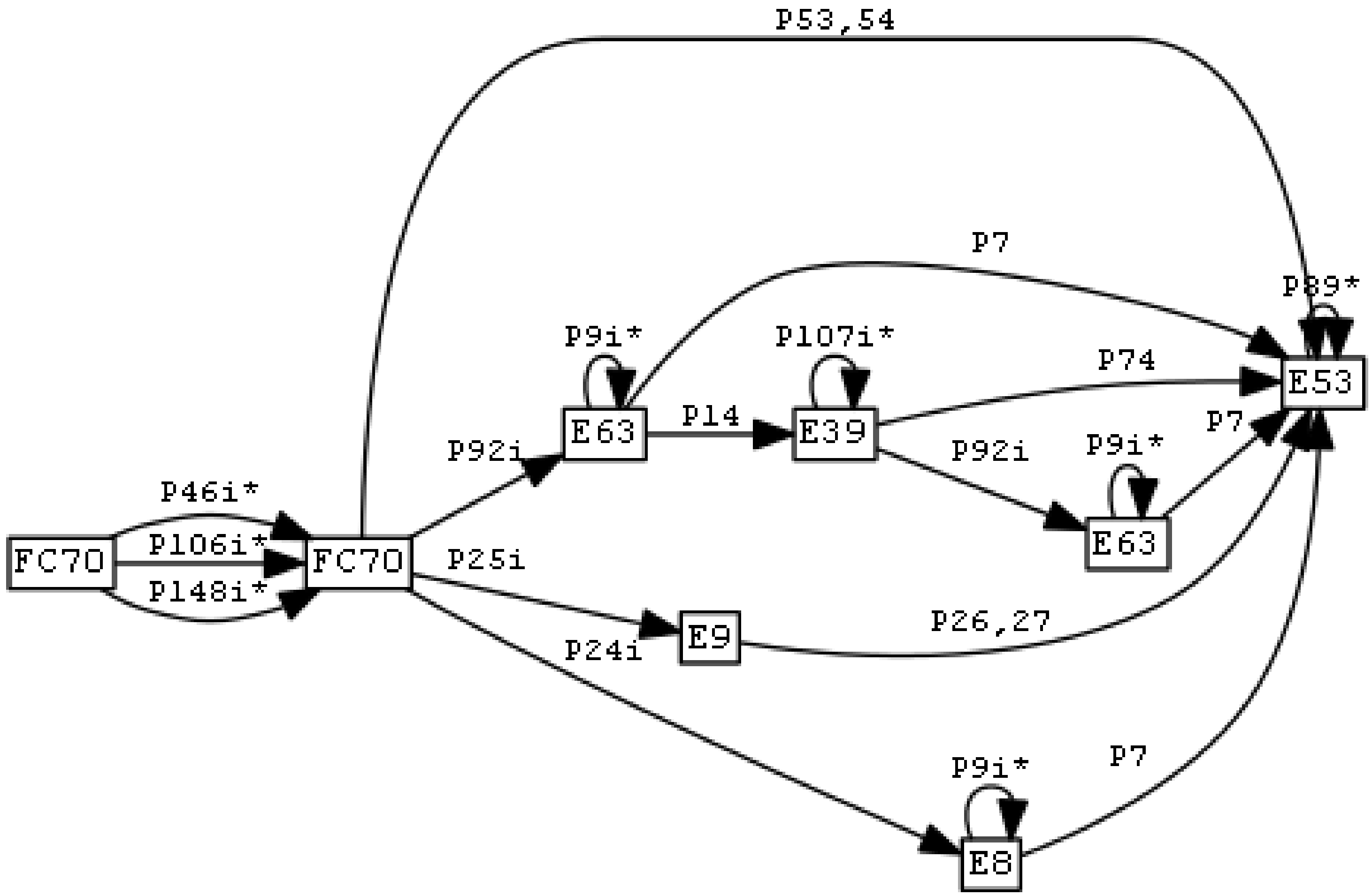
- is formerly or currently located at Place (that falls within another)*
- or was brought into existence (produced/created) by an Event (part of another)*
  - that happened at Place (that falls within another)*
  - or was carried out by an Actor (who is member of a Group)*
    - who formerly or currently has residence at Place (that falls within another)*
    - or was brought into existence (born/formed) by an Event (part of another)* that happened at Place (that falls within another)*
- or was Moved to/from a Place (that falls within another)*
- or changed ownership through an Acquisition (part of another)*
  - that happened at Place (that falls within another)*

Thing from Place: Definition (CRM Classes & Properties)

```
FC70_Thing --(P46i_forms_part_of* | P106i_forms_part_of* | P148i_is_component_of*)-> FC70_Thing:
 {FC70_Thing --(P53_has_former_or_current_location | P54_has_current_permanent_location)-> E53_Place:
  {E53_Place --P89_falls_within*-> E53_Place}
 OR FC70_Thing --P92i_was_brought_into_existence_by-> E63_Beginning_of_Existence:
  {E63_Beginning_of_Existence --P9i_forms_part_of*-> E5_Event:
   {E5_Event --P7_took_place_at-> E53_Place:
    {E53_Place --P89_falls_within*-> E53_Place}
   OR E7_Activity --P14_carried_out_by-> E39_Actor:
    {E39_Actor --P107i_is_current_or_former_member_of* -> E39_Actor:
     {E39_Actor --P74_has_current_or_former_residence  -> E53_Place:
      {E53_Place --P89_falls_within*-> E53_Place}
     OR E39_Actor --P92i_was_brought_into_existence_by-> E63_Beginning_of_Existence:
      {E63_Beginning_of_Existence --P9i_forms_part_of*-> E5_Event:
       {E5_Event --P7_took_place_at-> E53_Place:
        {E53_Place --P89_falls_within* -> E53_Place}}}}}}}
 OR E19_Physical_Thing  --P25i_moved_by-> E9_Move:
  {E9_Move --(P26_moved_to | P27_moved_from)-> E53_Place:
   {E53_Place  --P89_falls_within*-> E53_Place}}
 OR E19_Physical_Object --P24i_changed_ownership_through-> E8_Acquisition:
  {E8_Acquisition --P9i_forms_part_of*-> E5_Event:
   {E5_Event --P7_took_place_at-> E53_Place:
    {E53_Place --P89_falls_within*-> E53_Place}}}}
```

Thing from Place: Graphical Representation

- Although defined as a **tree** of property paths, the FR is better depicted as a **network** through a simple merge of leaf-level nodes



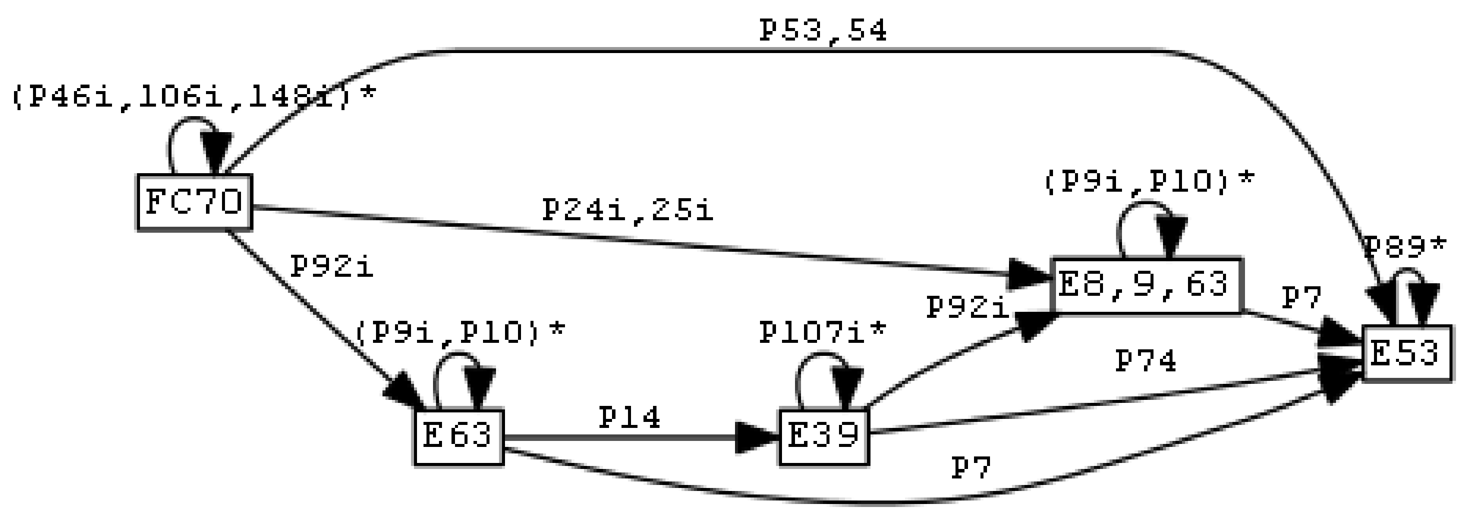
Thing from Place: SPARQL Query

```
select ?t ?p2 {
?t a FC70_Thing. ?t (P46i_forms_part_of* | P106i_forms_part_of* | P148i_is_component_of*) ?t1.
 {?t1 (P53_has_former_or_current_location | P54_has_current_permanent_location) ?p1}
 UNION
 {?t1 P92i_was_brought_into_existence_by ?e1. ?e1 P9i_forms_part_of* ?e2.
    {?e2 P7_took_place_at ?p1}
    UNION
    {?e2 P14_carried_out_by ?a1.
      ?a1 P107i_is_current_or_former_member_of* ?a2.
       {?a2 P74_has_current_or_former_residence ?p1}
       UNION
       {?a2 P92i_was_brought_into_existence_by ?e3. ?e3 P9i_forms_part_of* ?e4.
        ?e4 P7_took_place_at ?p1}}}
 UNION
 {?t2 P25i_moved_by ?e5. ?e5 (P26_moved_to | P27_moved_from) ?p1}
 UNION
 {?t2 P24i_changed_ownership_through ?e6.
   ?e6 P9i_forms_part_of ?e7. ?e7 P7_took_place_at ?p1}.
?p1 P89_falls_within* ?p2}
```

- This query is very complex and expensive, especially when you need to combine with other FRs into composite queries

Thing from Place: Corrections and Rationalization

- Allowed paths of mixed properties (e.g. P46i,P106i) at the beginning
- Allowed a loop P9i* at E9 (Move forms part of a bigger event) by merging the nodes E8, E9, and the second E63
- Allowed P10_falls_within in addition to P9i_forms_part_of (after consultation with the original authors)
- Skipped P26,P27: they are subproperties of P7, so it's enough to check for P7
- ➢ Simpler than the original, but still quite complex



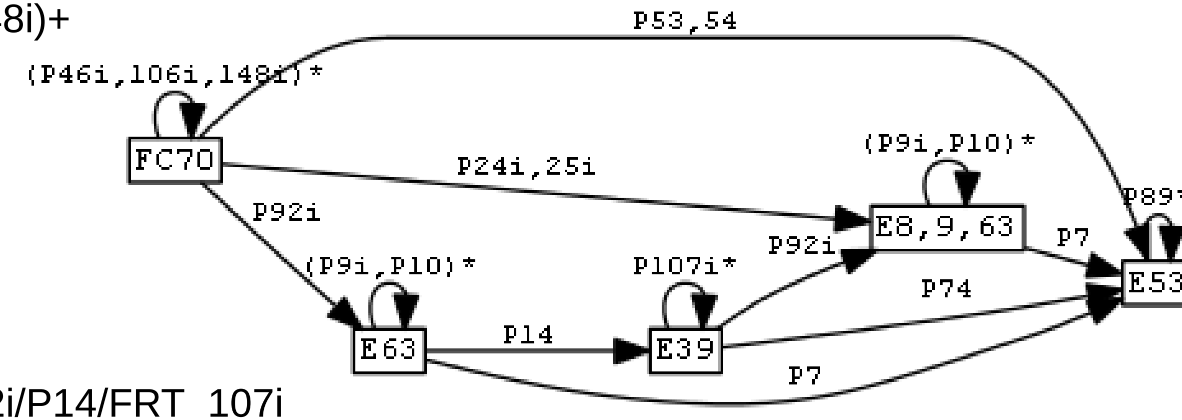
Inverses, Transitive properties

- Most CRM properties have inverse (symmetric properties are their own inverse)
  - FRs use CRM properties in both directions: forward (e.g. P53_has_former_or_current_location) and inverse (P24i_changed_ownership_through)
  - It's useful to rely on owl:inverseOf inferencing
- FRs use transitive closure to traverse "part" hierarchies
  - CRM has physical object parts, conceptual object parts, sub-places, sub-events
  - CRM scope notes suggest 14 properties (and inverses) should be transitive: P9 P10 P46 P86 P88 P89 P106 P114 P115 P116 P117 P120 P127 P148.
  - In addition to these "atomic" properties, disjunctions of properties often also need to be declared as transitive.
  - It's useful to rely on owl:TransitiveProperty inferencing.

No Reflexive Closure; Parallel-Serial Networks

- FRs often use reflexive-transitive closure (0 repetitions)
  - E.g. Thing from Place: can relate directly to a place, or to any of its super-places
  - We have opted **not** to use reflexive closure in the implementation, since it would generate a lot of trivial facts (self-loops).
  - We use disjunction instead: the iterated property is applied 0 times in the first disjunct, and *n* times in the second
- FRs are defined *mostly* as parallel-serial networks of properties
  - Can be seen from the SPARQL Property Path constructs and is explained below

Decomposing Thing from Place into sub-FRs



\# self-loops and simple disjunctions
FRT_46i_106i_148i := (P46i|P106i|P148i)+
FRT_9i_10 := (P9|P10)+
FRT_107i := P107i+
FRT_89 := P89+
FRX_53_54 := (P53|P54)
FRX_24i_25i := (P24i|P25i)
\# growing fragments
FRX_92i := P92i | P92i/FRT_9i_10
FRX_92i_14 := FRX_92i/P14 | FRX_92i/P14/FRT_107i
FRX_FC70_E8_9_63 := FRX_92i_14/P92i | FRX_24i_25i
FRX_FC70_E8_9_63_P7 := FRX_FC70_E8_9_63/P7 | FRX_FC70_E8_9_63/FRT_9i_10/P7
FRX7 := FRX_53_54 | FRX_FC70_E8_9_63_P7 | FRX_92i_14/P74 | FRX_92i/P7
FRX7_P89 := FRX7 | FRX7/FRT_89
FR7 := FRX7_P89 | FRT_46i_106i_148i/FRX7_P89

- "Sub-FRs" are auxiliary relations used to build up the final FR
- The numbering comes from CRM property and entity names
- Prefixes: FR: final result, FRT: transitive, FRX: non-transitive, FC70 or E: from/to that class

Implementing Parallel-Serial with RDFS and OWL

Pattern	Construct	Implementation
inverse	prop := ^prop1	prop1 owl:inverseOf prop2.
parallel	prop := prop1|prop2	prop1 rdfs:subPropertyOf prop. prop2 rdfs:subPropertyOf prop.
serial	prop := prop1/prop2	prop owl:PropertyChainAxiom (prop1 prop2).
transitive	prop := prop1+	prop1 rdfs:subPropertyOf prop. prop owl:TransitiveProperty
reflexive-transitive	prop := prop1 prop2*	Converted to the following: prop := prop1 | (prop1/prop2+)

- 3 RDFS and OWL constructs are sufficient to implement parallel-serial networks: subPropertyOf, TransitiveProperty, PropertyChainAxiom
  - In OWLIM, they are implemented using Rules
- So can't we stick to these constructs and not use OWLIM Rules at the application level?

Type Checking and Conjunctive Properties

- The original FR definition supposes type checks for every node (FC70, E63…), e.g.:
  ?x FR7_from_place ?y := ?x a FC70_Thing; ?x FR7 ?y; ?y a E53_Place.
- In many cases type checks can be skipped since they are implied by property ranges (e.g. P53 P54 P7 P47 P89 imply E53)
- In other cases type checks are required in the middle of a network. E.g. "Thing about X" is a family of FRs, where X is Thing, Place, Actor, Event
- For this we'd need conjunctive properties, which are not part of OWL2
  - OWL RL can be extended with role conjunctions without restrictions or increase in complexity
  - There is a proposal to include conjunctive properties in OWL 3

OWLIM

- A commercial semantic repository by Ontotext
  - Incremental assert **and** retract
  - High-performance: fully-materializing, replication cluster, strong benchmark results, good concurrent query response, cloud deployment
- Used in some landmark semweb projects
  - Runs BBC Sports, World Cup 2010 and the Olympics 2012
  - linkedlifedata.com semantic warehouse used by top-20 pharmaceuticals
- Quite a following in cultural heritage
  - The National Archives, The British Museum, Yale Center for British Art
  - FP7: 3D COFORM, CHARISMA, MOLTO
  - LOD.AC, Polish Digital National Museum

OWLIM Rules

- Allow simple unification and in/equality constraints
  - OWLIM implements OWL2 QL and RL using these rules
  - Custom rules are treated just like OWL (system) rules
  - E.g. sub-property, transitive, inverse reasoning:
    x p1 y; p2 <rdfs:subPropertyOf> p2 [Constraint p1!=p2] => x p2 y
    p <rdf:type> <owl:TransitiveProperty>; x p y; y p z => x p z
    p1 <owl:inverseOf> p2; x p1 y => y p2 x
    p1 <owl:inverseOf> p2; x p2 y => y p1 x
- Advantages:
  - Speed: forward-chaining & full materialization (translated to Java bytecode for speed), so query answering is very fast
  - "Reversible": when a triple is retracted, all consequences with no other support are retracted
- Disadvantages
  - Inflexible: if rules are changed, the repository needs to be reloaded.
    (Better implement generic rules that work on TBox assertions about properties.)
  - Proprietary to OWLIM
    (Ontotext is considering proposed standard rule languages in future versions)
  - Don't support real negation (e.g. instance is **not** of a given class or its super-classes)

FR Implementation

- Once the FR is decomposed to sub-FRs, implementation is straightforward. E.g. this sub-FR is implemented as:
  FRT_46i_106i_148i := (P46i|P106i|P148i)+
  x <crm:P46i_forms_part_of> y => x <rso:FRT_46i_106i_148i> y
  x <crm:P106i_forms_part_of> y => x <rso:FRT_46i_106i_148i> y
  x <crm:P148i_is_component_of> y => x <rso:FRT_46i_106i_148i> y
  <rso:FRT_46i_106i_148i> <rdf:type> <owl:TransitiveProperty>
  - Important to extract common sub-FRs between FRs, to facilitate reuse
- We implemented 11 FRs of Thing:
  - refers to or is about Place; from Place; is/was located in Place
  - has met Actor; by Actor
  - refers to or is about Event; has met Event
  - is made of Material; is/has Type; used technique; identified by Identifier
- Use 44 CRM properties. Took 86 rules, 10 axioms, 26 sub-FRs

Bug in "Thing has met Event"

- Acquisition
  - Often modeled as E8_Acquisition (changes owner), E10_Transfer_of_Custody (changes keeper), E80_Part_Removal (removes object from old collection), E79_Part_Addition (adds object to new collection)
  - An event at which meet: object, buyer, seller, old collection, new collection
  - Object (E22_Man-Made_Object) is P46i_forms_part_of old collection before acquisition (E78_Collection) and new collection after acquisition (E78_Collection)
- FC70_Thing --FR12_was_present_at-> E5_Event :=

  FC70_Thing --(P46i_forms_part_of | P106i_forms_part_of | P148i_is_component_of)* ->
  FC70_Thing --P12i_was_present_at-> E5_Event:
  E5_Event --P9i_forms_part_of*-> E5_Event
- Causes all objects in a collection to have met (witnessed) the addition of all other objects in the collection!
  - For new objects: logically impossible. For old objects: useless
  - Quadratic growth of data, exponential slowdown of data loading
  - BM has 1.5M objects in its collection, so the slowdown is unbearable

How did this bug make me feel?

- Took a couple of hours of debugging triples to diagnose
- Inference is powerful, but may expose unintended consequences

- *Karakondjul (Greek and Bulgarian): poltergeist, house troll*

Performance

- A concern was expressed that materializing sub-FR triples may increase the repository size too much and slow it down?
- Small repository of RKD data
  - 11 Rembrandt paintings: 1.5M triples, including 0.5M object triples (complex data about each painting, researches, documents, etc) and 1M thesaurus triples (people, places, etc)
  - FRs added only 25.8k triples, which is 1.7% of the total data or 5.1% of the object data → no perceptible slowdown
- Medium repository of BM data
  - Over 150k BM objects, about 20M triples
  - FR searches show no noticeable slow-down
  - Pending: all 1.5M BM objects
- OWLIM performs well on 10s B triples
  - Examples: linkedlifedata.com (public), The National Archives, BBC
  - So increases in the number of triples up to 50% are trivial
- Compare the raw SPARQL query on slide 13

Thanks for your attention!

- Questions/Discussion

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